

THE SYNTHESIS AND DISINTEGRATION
OF ATOMS AS REVEALED BY THE
PHOTOGRAPHY OF WILSON
CLOUD TRACKS

A DISSERTATION
SUBMITTED TO THE GRADUATE FACULTY
IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEPARTMENT OF CHEMISTRY
1930

BY
HUGH A. SHADDUCK

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THE SYNTHESIS AND DISINTEGRATION OF ATOMS AS REVEALED BY THE PHOTOGRAPHY OF WILSON CLOUD TRACKS

BY WILLIAM D. HARKINS AND HUGH A. SHADDUCK

KENT CHEMICAL LABORATORY, UNIVERSITY OF CHICAGO

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In 1923 Harkins and Ryan¹ developed and applied a procedure capable of revealing new details concerning the process of atomic disintegration. The initial discovery of the disintegration of light atoms was made by Rutherford,² who designed a method in which the scintillation apparatus of Crookes was so modified as to show when long range H-particles or protons are ejected from atom nuclei bombarded by alpha particles.

Harkins and Ryan considered that similar modification of the cloud track apparatus of Wilson would make it capable of exhibiting a greater part of the mechanism of disintegration.

That the photography of Wilson cloud tracks had not been used earlier for the purpose is undoubtedly due to the fact that the disintegration of atoms under bombardment is such a rare event that this method had not appeared to others as suitable. It will be shown later, too, that the change in the source of alpha rays, from the polonium applied earlier to a source such as ThC or RaC, which emits fast rays, was essential to the success of the method.

By the use of the extraordinarily fast rays from ThC, Harkins and Ryan obtained 11,000 photographs in nitrogen and 20,000 in argon, which corresponded to about 36,000 α -tracks of 8.6 cm. range in nitrogen and 70,000 in argon. That no H-disintegrations of the ordinary type were obtained in this work was partly due to the fact that a considerable part of the work was carried out in argon, which disintegrates less often than nitrogen, and partly to a statistical accident.

Two years later Blackett,³ by the use of the procedure applied earlier by Harkins and Ryan, obtained 22,000 photographs in nitrogen. In these eight disintegrations of nitrogen atoms to give protons were obtained and it was found that in each of these rare instances a fast alpha particle attaches itself to the nucleus of the nitrogen atom.

The purpose of this paper is to present the results obtained from 34,000 photographs not previously reported of α -ray tracks in nitrogen. These contained an average of slightly more than 12 alpha tracks each, so that about 270,000 tracks of 8.6 cm. and 145,000 tracks of 4.9 cm. range were obtained.

Figure 1 shows the arrangement in a plane of the tracks in one of the cases in which a fast α -particle attaches itself to the nucleus of a nitrogen atom. This probably forms momentarily the nucleus of an atom of

fluorine, which disintegrates almost at once to give a fast H-particle or proton, and the nucleus of a heavier atom, presumably that of oxygen of mass 17. All three tracks lie in a plane. The angle θ between the

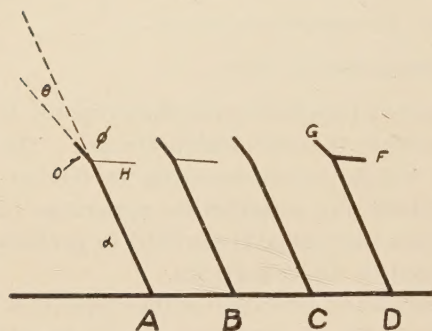


FIGURE 1

A designates the angles and rays; B shows the tracks as they occur in the ionization chamber in fork 1, a disintegrative-synthesis; except that the relative intensities are represented much better by A. C indicates the appearance fork 1 would exhibit provided the H-track were too dim to be seen; D indicates the characteristics of an elastic collision in which the α -particle rebounds along the track F. In this case there is a noticeable difference in the relations of the angles θ and ϕ .

direction of the track of the α -particle and that of the H-particle is 118° . The photograph indicates that the track of the proton has only about *one-sixth* to *one-tenth* the intensity of that of the α -particle or of the oxygen atom. Figure 1A designates the respective tracks and angles; figure 1B represents the combines synthesis and disintegration; and figure 1C illustrates what would be formed provided the track of the H-particle should be so faint as to be invisible. Figure 1D illustrates the marked difference in the appearance when the α -particle rebounds in the case of an ordinary (but extremely rare) collision. Here the dim track is not present and the angles are noticeably different.

Figure 2 is a reproduction of a photograph of the disintegrative-synthesis or atomic metathesis represented by figure 1B.

Table 1 exhibits the characteristics of two abnormal forks.

TABLE 1
CHARACTERISTICS OF FORKS WHICH REPRESENT NON-ELASTIC COLLISIONS

	ϕ	θ	R_α	$V_\alpha \times 10^{-9}$	$V_p \times 10^{-9}$	R_p	$V_n \times 10^{-9}$	R_n	E_2/E_1
Fork 1	$118^\circ 32'$	$15^\circ 21'$	6.3	1.86	2.7	19.6	0.534	0.43	0.89
Fork 2		51°	ca. 7						> 1.0

R = remaining range of α -particle; the distance the α -particle would have traveled beyond the point of the fork if the collision were not incurred.

V = velocity of the α -particle in cm. per second immediately before the collision.

V_p = velocity of the proton immediately after its escape from the heavy nucleus.

R_p = range of the proton, or H-particle.

V_n = velocity of the oxygen nucleus immediately after the escape of the proton.

R_n = range of the nucleus of the oxygen atom.

E_2/E_1 = kinetic energy of the H-particle plus that of the oxygen atom, divided by the kinetic energy of the α -particle immediately before impact. $1 - E_2/E_1$ represents the loss of kinetic energy due to the non-elastic impact, and is presumably stored up in the oxygen nucleus of mass 17.

Fork 1 represents a case in which it seems certain that the α -particle attaches itself to the nucleus of a heavier atom, and that a proton is emitted. The appearance of the dim track is, as exactly as can be determined, just that of the track of an H-particle. It is a straight line, and, as has already been stated, has on the original film only about one-tenth the intensity of the tracks of the α -particle and the oxygen atom. Furthermore, the relation between the values of the angles θ and ϕ is not con-

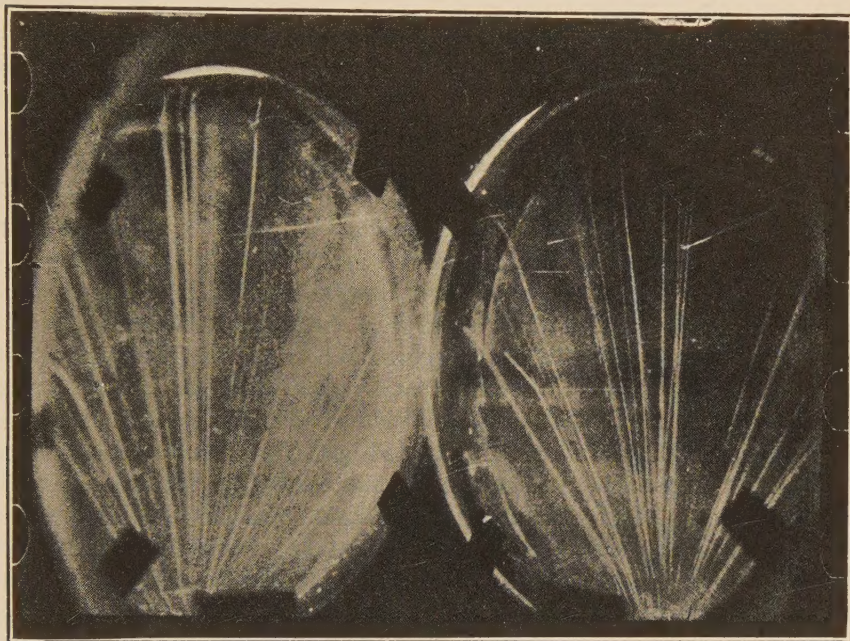


FIGURE 2

Two views at right angles of the non-elastic collision represented in figure 1B. At the left of each view an α -particle impinges upon the nucleus of a nitrogen atom and unites with it. An extremely faint straight track extends horizontally to the right of the fork and is due to a proton or H-particle emitted, at high speed. This has a range of 19.6 cm. in air at 15° and 760 mm. pressure. The track of the oxygen atom which is formed slants upward to the left from the fork. The left-hand view is overexposed as a result of an irregularity in the lighting, but the track of the H-particle is easily visible on the original negative.

sistent with the assumption that the dim track is due to a rebound of the α -particle. Although very many of such rebounds have been photographed in this laboratory, not one of them exhibits such a dim track. If this were merely an elastic collision then the ratio of the atomic masses would be given by

$$\frac{m}{M} = \frac{14}{4} = \frac{\sin \phi}{\sin (2\theta + \phi)}.$$

By the application of this equation to fork 1 the result $3.5 = 1.7$ is obtained, and it has not been possible upon repetition of the measurements to obtain results consistent with this equation, so the collision seems to be non-elastic.

The evidence that fork 2 represents a similar disintegrative synthesis is not so good, since this collision took place near the edge of the cylinder and the tracks are too diffuse for exact measurement. However, when all reasonable allowances are made for the inaccuracies of measurement it is impossible in any case to meet the conditions of both conservation of momentum and conservation of kinetic energy. The track attributed to hydrogen is also much more dim than that of the α -particle or of the heavy nucleus. What may seem to make this case a doubtful one is that the calculations indicate that energy is released from the nuclei and appears as kinetic energy, whereas with fork 1, and all but one of those found by Blackett, kinetic energy disappears. The minimum value of E_2/E_1 obtained from the calculations is about 1.1. There seems little doubt that with nitrogen E_2/E_1 is usually less than unity, and it may require much additional experimental work to determine with entire definiteness if in exceptional cases energy may be released from, instead of stored up in, the oxygen nucleus. Whatever the significance of fork 2 may be, it seems almost certain that the collision which it represents is inelastic.

The number of disintegrations obtained in this work is only one-fourth the number obtained by Blackett in the photography of the same number of tracks, but this smaller number seems to be in much better agreement with the reports concerning such yields in the papers of Rutherford and Chadwick (see also Petterson, "Atomzertrümmerung," page 138),⁴ even when allowance is made for the fact that they used much slower rays. From this point of view the larger number of disintegrations seems to be an accident, not at all remarkable when the number of events is in any case so extremely small.

Petterson and Kirsch consider that many H-tracks may be so dim as to be entirely overlooked in the photographs. They infer that short H-tracks might be more difficult to find than those of long range. Now the work in Vienna indicates that such tracks would have ranges as low as 2 cm., instead of the 18 cm. or more found thus far by the photographic method. Although we have not worked with H-particles of such a short range it would seem that they should be much brighter than the initial part of the tracks of the fast rays, and it is only the initial portion which is visible in the photographs. However, with the short rays the angle of deviation (θ) of the heavy nucleus may be so slight as to lead the observer to the conclusion that he is dealing with a straight track. Thus his attention is not called to this specific point in the picture. Nevertheless, the H-track of fork 1 is, though dim, so very distinct on the original film that

it seems probable that we have not missed more than one or two such events, even if the angle θ has been so small that it has not been recognized.

The minimum velocity for the alpha particle which has thus far been recognized as giving rise to an atomic disintegration corresponds to a remaining range of 6.2 cm., so that polonium, which gives a range (at 15° and 760 mm.) of only 3.9 cm., gives α -rays of far too small an energy (5.2×10^6 volts) to have given rise to a single one of the ten disintegrations thus far discovered. The minimum amount of energy which has proved successful in causing such a disintegrative synthesis corresponds to 7 million volts. Here, as is customary, the voltage is that required to give an electron the specified energy. Thus 3.5 million volts would be necessary to give an α -particle the required velocity.

Up to the present the photographic method has not demonstrated the non-occurrence of disintegrations which give short H-rays, though the results are not favorable to their existence. The writers are engaged in a more thorough search of the film for such events.

The procedure followed in the hunt for the tracks of protons is to look over the film with great care, and also to cut out every section which shows the slightest line in any region except where the α -particle has an extremely slow speed. If a fork exhibits two bright stubs (G , F , Fig. 1D) then the existence of an H-track is not suspected. Also if no stub F is found, only an ordinary fork is indicated, provided the bright track (G , Fig. 1D) is too long to indicate an oxygen atom (in general longer than about 0.5 cm.). Forks in which no visible stub G occurs, but in which the track beyond the bend is short (Fig. 1C), are examined with extreme care.

The measurements reported in this paper were made by a new method which may be called the "Mesh Plate Method." It consists in the establishment in the ionization chamber, which consists of a cylinder of optical glass, of a system of coördinates in space. A circular plate of yellow brass was made of such a size as to fit the cylinder with a clearance of about 0.5 mm. This was ruled on the milling machine into squares of 1 sq. mm. area by lines 0.1 mm. in diameter. These lines were then filled with tin solder and the brass surface blackened by the use of ammoniacal ammonium carbonate. This gave very uniform, silver-white lines against black on an entirely plane surface, since the surface was planed prior to the blackening.

The mesh plate is then set on the brass piston, which closes the bottom of the ionization chamber and fits inside a cylinder of brass below the glass. The mesh plate is set in an exact position by the use of a stand with three legs fitted with screws. The bottom of each leg fits a fine screw hole in the top of the piston. By the use of the fixed mirrors, used in obtaining two photographs at right angles of each set of α -tracks, two photographs, at right angles, are taken of the mesh plate. The piston is

then raised a distance of 0.02 cm. and another pair of photographs taken. This operation is repeated until the top of the chamber is reached.

In order to find the position in space represented by any point in the photographs, it is only necessary to find the point in both photographs. The film which shows the point is then placed in a special apparatus such that the position of the mesh-plate pictures can be moved, while that of the tracks which contains the point remains fixed, until the readings for the point on both projections of the mesh-point picture are the same. The x - and y -coordinates of the point are given by the markings on the mesh plate (except that tenths are estimated), and the number of the mesh-plate photograph gives the z -coordinate. The use of this method of measurement eliminates errors due to the lens, which was, however, a Taylor-Cooke-Hobson lens of the best grade. Also errors due to the glass at the top of the cylinder, and to the glass of the mirrors are eliminated. Nevertheless, all of these were made optically plane in Ryerson Physical Laboratory. If the lines are too short or too highly curved, other methods should be used. The mesh-plate method has the great advantage that it allows not only for all errors due to the use of the lens but also for differences in magnification due to the use of two views at right angles.

In this work two non-elastic collisions have been found. In order to specify the number of elastic collisions it is necessary to give an arbitrary distinction between a collision on the one hand and a close approach of the alpha particle to the nucleus of the other atom. It will be considered that any fork represents a collision if the angle of deviation (ϕ) is equal to or greater than 90° , provided the impact is elastic. If the impact is inelastic the lack of elasticity is considered as evidence that a "collision" has occurred. All other forks are classed as "close approaches." Harkins and Ryan obtained about ten collisions. In the work reported here all of the collisions have been found, but have not been counted accurately. However, one-third of the film has given nine elastic collisions in about 138,000 tracks. Since the diameter of the ionization chamber is 6.3 cm., only about 0.5 of the range of the tracks of range 8.6 cm. (at 15° and 760 mm. pressure) is represented in the photographs, but almost the complete length of those of 4.8 cm. range is given. The number of elastic, but not that of the non-elastic, collisions would be increased if the whole range were shown.

According to the Hydrogen-Helium theory of Harkins and Wilson⁵ the atoms have been built up largely by the aggregation of α -particles, or by the addition of smaller aggregates of protons and electrons which almost always give to the complex nucleus a composition corresponding to a certain whole number of α -particles, either with or without additional electrons. There is considerable evidence that the half- α -particle, p_{2e} , may also be of importance. To what extent such α -particles preserve their indi-

viduality in the complex nucleus is a moot question. Alpha particles are emitted spontaneously from the nuclei of very heavy atoms, and are now found to unite with those of light atoms. It seems probable that the emission of the proton, which has served as an indication of the addition of the α -particle, is not essential to the synthesis. Thus, it is quite likely that when oxygen or carbon has been used in the chamber, the addition of an α -particle may have occurred. The great difficulty in recognizing such an event, in the absence of a very powerful magnetic or electrical field, lies in the fact that the only apparent result is the shortening of the track of the α -particle. It seems probable that the positiveness of the double charge of the α -particle is an important factor in causing the expulsion of a positively charged proton when nitrogen is bombarded.

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¹ Harkins and Ryan, *J. Amer. Chem. Soc.*, **45**, 2095 (1923).

² Rutherford, *Phil. Mag.*, **37**, 538 (1919).

³ Blackett, *Proc. Roy. Soc.*, **107**, 349 (1925).

⁴ Petterson and Kirsch, *Atomzertrümmerung* (1926), p. 138.

⁵ Harkins and Wilson, these PROCEEDINGS, **1**, 276 (1915); *J. Amer. Chem. Soc.*, **37**, 1367 (1915); *Phil. Mag.*, **30**, 723 (1915); and later papers.

